Civilian Research Project

USAWC Fellow

Additive Manufacturing: Implications to the Army Organic Industrial Base in 2030

by

Colonel Jon R. Drushal
United States Army/Chemical Corps

United States Army War College
Class of 2013

The U.S. Army War College is accredited by the Commission on Higher Education of the Middle States Association of Colleges and Schools, 3624 Market Street, Philadelphia, PA 19104, (215) 662-5606. The Commission on Higher Education is an institutional accrediting agency recognized by the U.S. Secretary of Education and the Council for Higher Education Accreditation.

REPORT DOCUMENTATION PAGE	*Form Approved* *OMB No. 0704-0188*

1. REPORT DATE *(DD-MM-YYYY)*
xx-04-2013

2. REPORT TYPE
CIVILIAN RESEARCH PROJECT

3. DATES COVERED *(From - To)*

4. TITLE AND SUBTITLE
Additive Manufacturing: Implications to the Army Organic Industrial Base in 2030

5a. CONTRACT NUMBER

5b. GRANT NUMBER

5c. PROGRAM ELEMENT NUMBER

6. AUTHOR(S)
Colonel Jon R. Drushal
United States Army/Chemical Corps

5d. PROJECT NUMBER

5e. TASK NUMBER

5f. WORK UNIT NUMBER

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)
Mr. Magnus Nordenman
Atlantic Council Brent Scowcroft Center on International Security

8. PERFORMING ORGANIZATION REPORT NUMBER

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)
Colonel Dave Dworak

U.S. Army War College, 122 Forbes Avenue, Carlisle, PA 17013

10. SPONSOR/MONITOR'S ACRONYM(S)

11. SPONSOR/MONITOR'S REPORT NUMBER(S)

12. DISTRIBUTION / AVAILABILITY STATEMENT
Distribution A: Approved for Public Release. Distribution is Unlimited.

13. SUPPLEMENTARY NOTES
Word Count: 6363

14. ABSTRACT
What disruptive technology is on the horizon that will change the way the United States and the world operate and could fundamentally change the way the Army Organic Industrial Base (AOIB) operates? There are many who believe that Additive Manufacturing (AM) is that technology. I propose to research how AM could affect the AOIB and how the resulting manufacturing efficiencies could drive down cost and increase flexibility and responsiveness within DoD. This paper will look at several aspects of AM starting first with defining it, the status of the technology, current uses within DoD, advantages and disadvantages, example impacts to an AOIB process, and conclude with recommendations on a path forward. The impacts of the AM process on the AOIB will be illustrated by looking at a specific process on Anniston Depot. The analysis will look at the most relevant and fastest growing AM application - parts manufacturing and refurbishment. If approached correctly, DoD stands to save significant resources within the AOIB.

15. SUBJECT TERMS
Disruptive technology, supply chain, certification, strategy, design, integration, refurbish, intellectual property

16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
a. REPORT	b. ABSTRACT	c. THIS PAGE			19b. TELEPHONE NUMBER *(Include area code)*
UU	UU	UU	UU	36	

USAWC CIVILIAN RESEARCH PROJECT

Additive Manufacturing: Implications to the Army Organic Industrial Base in 2030

by

Colonel Jon R. Drushal
United States Army/Chemical Corps

Mr. Magnus Nordenman
Atlantic Council Brent Scowcroft Center on International Security
Project Adviser

Colonel Dave Dworak
U.S. Army War College Faculty Mentor

This manuscript is submitted in partial fulfillment of the requirements of the U.S. Army War College Fellowship. The U.S. Army War College is accredited by the Commission on Higher Education of the Middle States Association of Colleges and Schools, 3624 Market Street, Philadelphia, PA 19104, (215) 662-5606. The Commission on Higher Education is an institutional accrediting agency recognized by the U.S. Secretary of Education and the Council for Higher Education Accreditation.

U.S. Army War College
CARLISLE BARRACKS, PENNSYLVANIA 17013

Abstract

Title:	Additive Manufacturing: Implications to the Army Organic Industrial Base in 2030
Report Date:	April 2013
Page Count:	36
Word Count:	6363
Key Terms:	Disruptive technology, supply chain, certification, strategy, design, integration, refurbish, intellectual property
Classification:	Unclassified

What disruptive technology is on the horizon that will change the way the United States and the world operate and could fundamentally change the way the Army Organic Industrial Base (AOIB) operates? There are many who believe that Additive Manufacturing (AM) is that technology. I propose to research how AM could affect the AOIB and how the resulting manufacturing efficiencies could drive down cost and increase flexibility and responsiveness within DoD. This paper will look at several aspects of AM starting first with defining it, the status of the technology, current uses within DoD, advantages and disadvantages, example impacts to an AOIB process, and conclude with recommendations on a path forward. The impacts of the AM process on the AOIB will be illustrated by looking at a specific process on Anniston Depot. The analysis will look at the most relevant and fastest growing AM application - parts manufacturing and refurbishment. If approached correctly, DoD stands to save significant resources within the AOIB.

Additive Manufacturing: Implications to the Army Organic Industrial Base in 2030

We must pursue science and research that enables discovery, and unlocks wonders as unforeseen to us today as the surface of the moon and the microchip were a century ago. Simply put, we must see American innovation as a foundation of American power[1]

-President Barack Obama

Disruptive technology is a term coined by Harvard Business School professor Clayton M. Christensen to describe a new technology that unexpectedly displaces an established technology.[2] Disruptive technologies such as the light bulb, steam engine, or the microchip have over the course of centuries changed the way humankind has been able to live, produce, and fight. Corporate America has embraced Additive Manufacturing (AM) or what is also known as 3-D printing as the best bet for the next disruptive technology. There is consensus that AM could be the single biggest disruptive technology with global impacts since the microchip and one which could actually reverse the trend of globalization as we know it today.

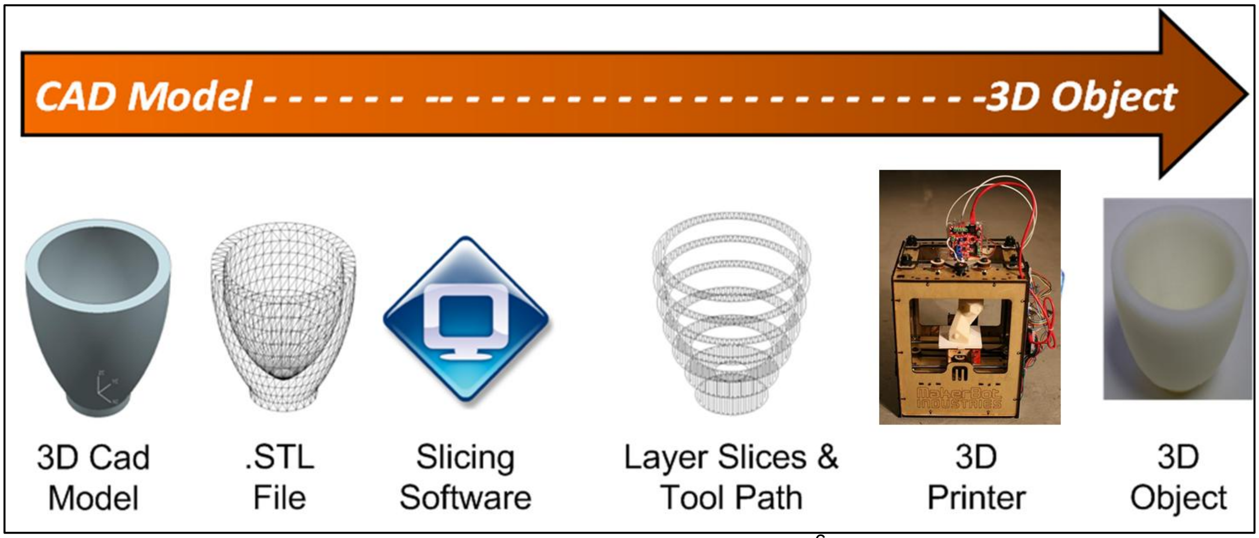
The objective of this paper is to look at the possible effects of AM on the Army Organic Industrial Base (AOIB) by 2030 and the resulting efficiencies that may be gained by transitioning, at least in part, to AM. There is no doubt that AM will at some level become a key component of the Department of Defense (DoD) manufacturing blue print. But, the question remains what level of commitment will the DoD have to take early advantage of this technology. There are a number of indications from key government officials that point to acceptance of the need to adopt new practices. President Obama stated in his January 2012 Strategic Guidance that DoD should both encourage a culture of change and be prudent with its "seed corn," balancing reductions necessitated by resource pressures with the imperative to sustain key streams of

innovation that may provide significant long-term payoffs.[3] As Chairman of the Joint Chiefs of Staff, Admiral Mullen stated that we must continue to maintain our margin of technological superiority and ensure our Nation's industrial base is able to field the capabilities and capacity necessary for our forces to succeed in any contingency.[4] Recently, Heidi Shyu, the Army's top acquisition official, signaled her intention for the Army to take this opportunity to think big – big as in figuring out what the Army will look like in 2042. Shyu has ordered the Army to formulate a 30-year modernization strategy to plan what soldiers will need in terms of equipment, weapons and vehicles in the next three decades.[5] The evolving strategic level guidance for DoD is likely to foster an atmosphere of innovation and new thinking that could propel the AOIB into the next generation of technological advances in manufacturing. This paper will examine the opportunities and barriers to fully integrate AM into the AOIB. It will define AM, look at the status of the technology today including current DoD uses, weigh its advantages and disadvantages providing examples of impacts on the AOIB, and conclude with recommendations for DoD's path forward.

Defining AM

The AM process builds a product by adding layer upon layer, adding material or "feedstock" as the product is built. The opposite of AM is Subtractive Manufacturing (SM) which removes material from a larger product. The AM process begins with the creation of a 3-D model of the product, usually by computer-aided design (CAD) software or a scan of an existing product. Specialized software slices this model into cross-sectional layers, creating a computer file that is sent to the AM machine. The AM machine then creates the product by forming each layer via the selective placement of

material (Figure 1). Types of AM include fuse deposition modeling which lays down liquefied plastic or metal through a thin filament that forms into the desired shape as it hardens; stereo-lithography which uses ultraviolet lasers to cure a photopolymer resin one layer at a time; and selective laser sintering (SLM) which uses a high powered laser to selectively fuse powders into the desired shape.



(Figure 1 – The AM Process[6])

The SLM process, commonly used when building or repairing metals based parts, should be of particular interest to the AOIB community. The SLM process uses a high powered laser to fuse fine metal powders together layer by layer directly from CAD data to create functional metal parts. After each layer a powder re-coater system deposits a fresh layer of powder in thicknesses ranging from 20 to 100 microns. The SLM system uses commercially available gas atomized metallic powders to produce fully dense metal parts in materials including titanium, stainless steel, cobalt chrome and tool steel. In addition to CAD data, other types of data may be used to drive AM processes such as three dimensional (3-D) scan data (for reverse engineering) and Digital Imaging and

Communications in Medicine (DICOM) data (for making physical representation of 3-D medical imagery).

State of AM Technology

The commercial AM industry is at an inflection point, poised to increase from $1.3 billion in sales and services today, to $3 billion by 2016 and $5.2 billion by 2020.[7] Even though the technology is 20 to 25 years old, it is showing signs of significant growth with commercial companies jockeying for key business sector advantage. 3D Systems is a clear industry leader with revenues up 52 percent from 2011 to 2012 and new product revenues up 60 percent in the same time frame. In 2012, the stock price of 3D Systems has shot up 185 percent, or an 18-fold increase over the S&P (a 10 percent increase).[8]

Just like any truly disruptive technology, it is not entirely clear to what extent or in which specific industries AM or 3-D printing will prove most disrupting. For now, the biggest players within the 2-D printing industry, companies such as HP and Epson, seem to be paying little attention to the 3-D printing market opportunities. Smaller companies are sensing new business opportunities and gaining name recognition. Makerbot with its Replicator 3-D printers has been at the forefront of the home 3-D printer market over the last several years and have recently opened the country's first retail 3-D printing store in Manhattan, New York City. There are others making impacts as well with the funding to develop and market these new systems. Formlabs promises to make the Form 1 3-D Printer that meets professional designer quality standards and at the same price as the Replicator Printer. Even Staples has joined the movement by teaming with Mcor Technologies Ltd., launching the 3-D printing service "Staples Easy

3-D”. Easy 3D will offer consumers, product designers, architects, healthcare professionals, educators, students and others low-cost, color, photo-realistic 3-D printed products. Customers will simply upload electronic files to the Staples Office Centre and pick up the models in their local Staples store, or have them shipped to their address.[9]

Beyond the 3-D printing market, large aerospace companies such as Boeing, GE Aviation, and Airbus are hard at work qualifying AM processes and materials for flight. Boeing now has 200 different AM part numbers on 10 production platforms for both military and commercial jets.[10] Aurora Flight Sciences and Stratasys fabricated and flew a 62-inch wingspan aircraft with a wing composed entirely of AM components. The wing was designed by Aurora and manufactured by Stratasys utilizing their Fused Deposition Modeling (FDM) 3-D printers.[11]   3-D printing is not confined to manufacturing processes or products. There are companies looking at printing human organs, food, and other types of everyday items. Some designers are already printing ready-to-wear shoes and dresses from plastic and nylon materials. Iris van Herpen, a Dutch fashion designer, has produced striking 3D-printed collections for the catwalks. No one can yet print leather, but the ability is on the horizon.[12]

AM Technology Advantages and Disadvantages

While there are both advantages and disadvantages to AM technology today, the positive future impacts to manufacturing in particular are tremendous. AM technology advantages have drawn worldwide interest in the technology and define the parameters of a disruptive technology. Arguably, AM could reduce energy use by 50 percent and reduce material cost by up to 90 percent compared to traditional manufacturing.[13]

The first and probably most significant advantage is that products would be made at the Point of Requirement (POR). This is “just in time” logistics in its truest form as products are printed on demand. Consequently, this eliminates the need for large warehousing requirements thus reducing the millions spent on holding stocks for traditional supply production. For manufacturing, reduced inventories will change the old business model of lowering prices through economies of scale. Companies will now maintain digital inventories versus physical inventories by maintaining the CAD files that support production. Utilizing AM technology could lower the cost per unit without expansion. Assembly lines and supply chains can be simplified, reduced or eliminated, thus reducing costs as products/parts are re-organized within a single facility. Supply chain reductions will have enormous impacts on global transportation requirements. There will be a corresponding reduction in labor costs as entire workspaces will be filled with AM machines executing unmonitored, overnight builds. While AM may reduce the number of workers with specific job required skill sets, it creates an entirely new field of work for the U.S. labor force. In fact, Virginia Tech is looking at creating classes in AM process and design.[14] Assembly requirements (parts integration) are reduced thus decreasing tooling and manufacturing, numbers of parts, assembly, certification paperwork, and maintenance. To capitalize on parts integration, it is important to determine through design what level of component printing is desired. You cannot design an engine that is printed as a single component and if a part fails, you have to print the entire engine again. Design efforts will have to allow for component flexibility. The time between design iterations is reduced while at the same time opening up an ability to create complex geometries that cannot be otherwise fabricated resulting in

components that are stronger, lighter, and use less materials. Lot size minimums become a thing of the past. And finally, with the reduction in energy consumption, there is a corresponding reduction in the carbon footprint thus making the technology more environmentally friendly.

The known shortcomings of AM are the focus of an intense level of effort in both the commercial Research and Development (R&D) and DoD Science and Technology (S&T) communities. The most glaring weakness is the speed of parts production, relegating it currently to niche production jobs. AM is currently not built for economies of scale (Approximately 1.5 vertical inch per hour). Its niche is currently filling a specialization function, building specific parts for specific purpose. Although there is some mass production occurring within the commercial sector, large scale metals production remains a future goal. Another weakness is the quality, tensile strength, and uniformity of metals. According to Dr. John Seel, "Strain, strength, pop, and snap are what we are looking for and must be optimized to the device – thermal transfer issues are still a worry right now."[15] Industry standards must be developed for processes, parts, and materials and must include machine qualifications standards that improve machine-to-machine and part-to-part repeatability.[16] Many areas require work but the good news is that the commercial and defense Research, Development, Technology and Engineering (RDT&E) communities know it and are beginning to solve some of the issues.

Potential Drivers

The question now becomes how much and how quickly will AM replace the way we understand manufacturing today. According to LTC Brian Lamson, "AM will grow slowly

over time starting small and replacing common parts (we buy designs) and working our way up. This will also drive additional investment."[17] Nationally, it seems the Obama Administration has taken note. To foster the AM technology forward, the National Additive Manufacturing Innovation Institute (NAMII) was established with the goal of widespread adoption of AM to increase domestic manufacturing competitiveness. The NAMII is a pilot institute designed to foster public-private partnerships between industry, government, and universities. The NAMII collaborates on manufacturing technology among Army, Navy, Air Force, Defense Logistics Agency (DLA), Defense Advanced Research Projects Agency (DARPA), Department of Energy (DOE), National Science Foundation (NSF), National Institute of Standards and Technology (NIST), and National Aeronautics and Space Administration (NASA). The NAMII was awarded $30 million in initial federal funding that was matched by $40 million from the 65 entities involved in the new partnership.

Of particular interest to NAMII and the DoD is the establishment of standards for the technology on everything from machining to metals. Adoption of standards has begun through the American Society for Testing and Materials (ASTM) International F42 committee that currently has four subcommittees working towards standards in materials and processes, terminology, design, data formats, and test methods. Additionally, the NIST convened a workshop in December 2012 to specifically begin laying the groundwork for metals based standards.

While key industry analysts argue that AM is the next trillion dollar industry, clearly adoption of the technology is in its infancy but growing quickly. If a part can be produced conventionally at a reasonable cost and the volume is high, it is best to go

that route as opposed to AM. But, this will change quickly in the next 5 to 10 years as more and more parts are manufactured and then inserted into the assembly process or entire products begin to be built using AM parts. One early success is the Areion, built by Belgian Group T, which is the world's first car made almost entirely from 3D printed parts.[18] It must be noted that regardless of the level to which AM advances, there will always be a requirement for some level of SM or molding technologies for the foreseeable future.

<u>Current DoD Examples</u>

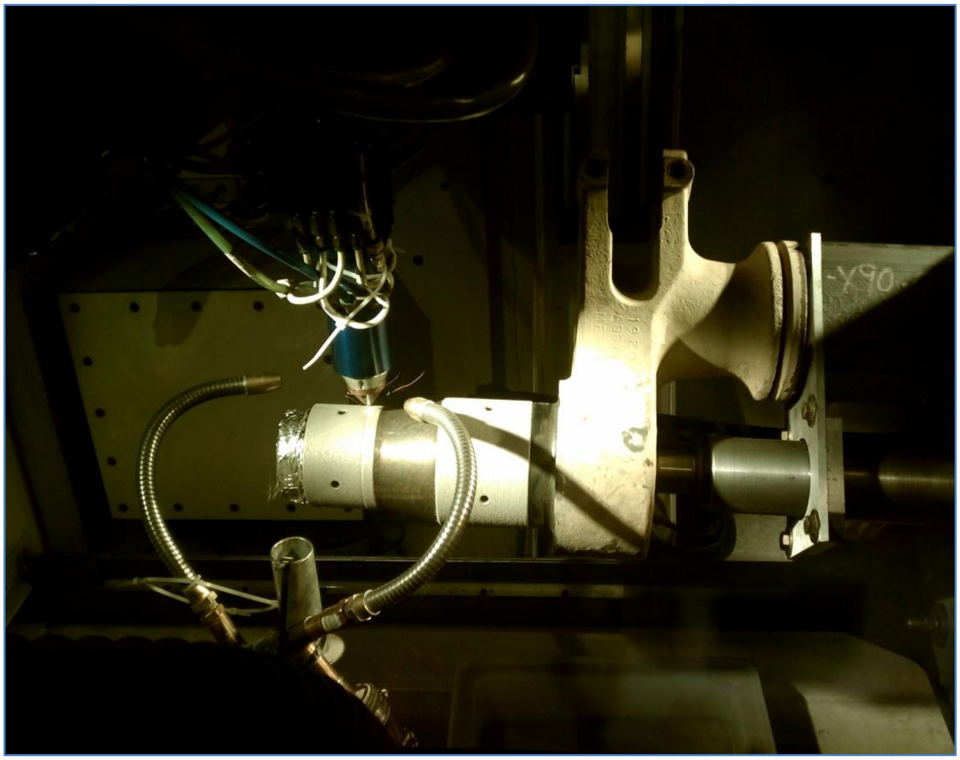
A large number of DoD organizations are currently experimenting with or actually using AM technology. The Rapid Equipment Fielding (REF) expeditionary lab for rapid prototyping -- deployed in Afghanistan since May 2012 -- is the first to use 3-D printing "down range in the fight," REF spokeswoman Ali Sanders stated.[19] According to the lab's product manager, Wes Brin, at a meeting at the Pentagon in July 2012, the REF's lab has already seen success in rapidly producing solutions to problems within days. He noted that soldiers experiencing problems with the life of a battery on a mine detector system went to the lab for help. The battery, which was supposed to last six to eight hours, would work for only about an hour in the heat in Afghanistan. Brin went on to say "Within six hours of a soldier coming into the lab, the engineers created an adapter that interfaced to the battery to allow it to charge to any military standard battery, and increased its lifetime to 48 hours."[20]

In September 2012, the U.S. Army Medical Command announced a solicitation to purchase a 3-D printer for the Walter Reed National Military Medical Center. Such a printer would be used to "fabricate pre-surgical physical models" as well as "guides,

templates, custom implants, rehabilitation devices, anatomical models with segmented anatomical features," among other uses. Another recent solicitation sought a printer for Army dentistry use. While the Army did not specify end use details, the printers are likely to be used for making dental prosthetics, an already common practice in commercial dental offices[21]

The Army's Research, Development and Engineering Command (ARDEC) and the Army's Edgewood Chemical Biological Center (ECBC), the Army's center for research on defending against a toxic attack, are doing significant AM work. At ECBC, researchers work in a lab with a number of high-end printers, and are designing printable holders for the military's Minehound bomb detectors. The Army recently revealed that ECBC is preparing to produce thousands of the holders — which are designed to take weight off soldiers' backs — and do so relatively quickly. "The fact that we could do this many designs and print them out and have them in their hands in one week gave the Army the option to choose between what works best for their application," Rick Moore, chief of the ECBC's Rapid Technologies Branch, said in a recent press release. "This is a good example of how we use the technology every day."[22]

The Anniston Army Depot is using a form of directed energy deposition AM called Laser Engineered Net Shaping (LENS) from Optomec to repair among other things, the Abrams Compensating Suspension Arm (Figure 2).[23] Because only worn surfaces are repaired using a wear resistant material with minimum heat effect on the original part, there are significant cost savings. Replacement cost of the suspension arm is $2000 and repair cost is $750 resulting in a savings of $1250 for each arm.

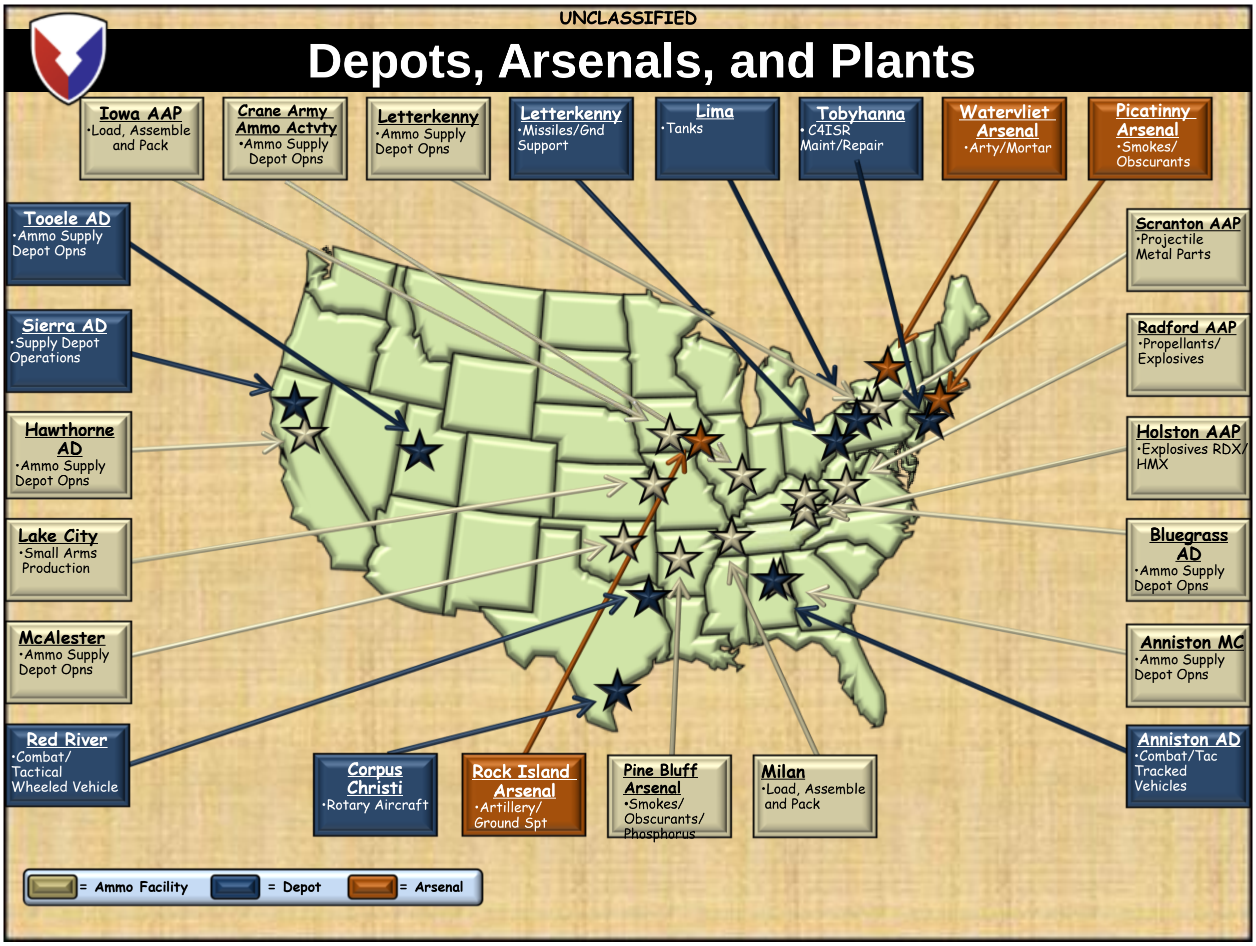


(Figure 2 - Additive Repair using Optimec LENS. Repair Part is an Abrams Compensating Suspension Arm)

The AOIB

The AOIB is well postured to take advantage of the positive aspects of AM. The AOIB, a subset of the larger Defense industrial base, is composed of resource providers, acquisition and sustainment planners, and manufacturing and maintenance performers.[24] The AOIB mission is to provide the resources, skills, logistics, maintenance and manufacturing capabilities to sustain the life cycle readiness of weapon systems in a reliable and efficient manner, while maintaining the ability to surge during contingency operations.[25] Figure 3 depicts the AOIB, which consists of eight depots, ten ammunition plants and centers, and four arsenals all under Army Materiel Command (AMC). Together with commercial industry, they constitute the backbone

and strength of the military's weapons system providers. The AOIB is guided by the U.S. Army Organic Industrial Base Strategic Plan (AOIBSP) which attempts to provide a highly responsive and cost effective enterprise. Currently, the AOIBSP covers only the Army's five primary maintenance depots (Sierra, Red River, Corpus Christi, Anniston, Letterkenny, and Tobyhanna) and three manufacturing arsenals (Pine Bluff, Rock Island, and Watervliet). An appendix to the plan will be published in the future on the



(Figure 3 – Depots, Arsenals, and Plants)

ammunition enterprise. The time horizon for the AOIBSP is 6-10 years, well inside most time spans for similar plans. The AOIBSP outlines the goals and objectives for the

industrial base to include capital investments, modernization, and Public Private Partnerships (PPP).

Potential Impacts of AM on the AOIB

The Obama administration is committed to revitalizing and transforming America's manufacturing sector. It has directed government agencies to give priority to those programs that advance the state of the art in manufacturing, with particular emphasis on government-industry-university partnerships and enabling technologies (such as robotics, materials development, and *additive manufacturing*) that benefit multiple sectors.[26] The key question is to what extent AM will potentially transform the AOIB. According to Jim Uribe, Chief, Industrial Planning Division, Joint Munitions Command, "AM can have a huge impact if it allows us to reduce production risk, increase readiness and efficiency, while at the same time allowing us to right size and modernize the ammunition base." [27] The adoption of AM may affect the AOIB vastly more than any other area within DoD.

The impacts of AM on the AOIB will be best illustrated by looking at a specific process and some of the variables that affect that process. The analysis will not be a detailed, facility by facility run down on the impacts nor the winners and losers resulting from the implementation of the technology. Its impacts can also be demonstrated by examining examples of the most relevant and fastest growing AM application - parts manufacturing and refurbishment. In fact, the parts manufacturing application has grown from 4 percent of total AM revenues in 2003 to nearly 20 percent in 2010.[28] While but a small sample, such parts analysis illustrates the resources that can be saved given some level of AM adoption within the industry.

This analysis looks out to the year 2030 and assumes that many of the barriers to AM have been resolved such as the speed of printing, metals and machining quality, thermal transfer, and Intellectual Property (Army owns the system technical packages allowing it to print any part without vendor proprietary barriers). It includes only parts that are steel or rubber variants and does not include electronics, optics, gun tube, etc. that will still require vendors and manufacturing processes (even by 2030) that may or may not include AM but are at the discretion of the vendor. While this may be an overly optimistic view, it should provide a glimpse into possible variations of technological integration into the AOIB depending on advances at the time. The outputs of the analysis will then need to be extrapolated to determine what is in the realm of the possible for the AOIB as a whole and provides a framework for long term strategic analysis by DA G4, AMC, and the Science and Technology (S&T) community.

Specifically, the analysis will look at the M1A1 Tank rebuild program at Anniston Army Depot (ANAD). The ANAD rebuilds an average of 278 (in FY12) tanks annually at an estimated cost to the services of $183.4 million (FY12). The tanks are either repaired to 10-20 standards or are overhauled (stripped and rebuilt from the ground up). The average cost to bring a tank to 10-20 standards is $746,000 (FY12) and to overhaul is $1.5 million (FY12).[29]

The current process for overhaul involves stripping the tank and then sending the parts to backshops based upon the type of part. At the backshops, procedures are established to determine which parts will be reclaimed and which are replaced. Reclaimed parts are sent to machine shops while replaced parts are turned in as scrap and the new part is brought forward from the ANAD warehouses. The tanks are then

re-assembled and prepared for shipment back to the owning unit. This is an oversimplification of the amount of work required to make this occur, but provides an outline of the process.

With the adoption of AM, the rebuild process would require a change where parts are reclaimed or replaced at the POR (ANAD) meaning, in theory, that the supply chain could be abolished outright. While tanks would still need to be stripped and then rebuilt, the cost structure and the way in which parts are provided would fundamentally change. The backshop process would remain unchanged except that reclaimed parts would be sent to large printing facilities where specifically designed AM machines would then repair the part to be re-installed (Figure 2). When it is determined a part needs to be replaced, a request could be sent to another large printing facility with differently designed AM machines to manufacture a new part.

Another of the myriad positive values of the AM process is that parts would be reclaimed or replaced on demand, meaning they will only be provided to the rebuild line when required. This would eliminate the requirement to forecast parts which are normally done 90-120 days out and in some cases, in excess of a year. Since there would be no long lead time parts, this would significantly reduce warehousing requirements and make the rebuild process more efficient. The elimination of the supply chain including vendor overhead, transportation costs, warehousing requirements, and labor in terms of warehouse management and machining requirements could result in significant cost savings.

In order to provide a snapshot of the potential cost savings, the table at Figure 4 provides the overheads associated with a small sample of parts from the suspension

system for an M1A1 Tank. It does not reflect the cost of the parts but looks specifically at overheads that can be significantly reduced when AM is utilized at the POR and on demand. Besides being a small sample size, the data does not reflect vendor overheads which could generate significant additional cost savings. With limited data, some assumptions must be made. First, the data is based upon 278 M1A1 rebuilds per year which averages to 23 per month and 6 per week. The workload will change greatly by FY and is certainly going to fall significantly in FY13 given current budget outlays. Since ordering, storage, and issue of parts is not an exact science, all calculations are

Part NOUN	Unit Cube	Storage Cost per Cube	Receipt Cost per Line	Issue Cost per Line	Qty per M1A1	Total Storage cost	Total Receipt cost	Total Issue Cost	Total DLA Overhead (estimated)
HOUSING, STEERING (LARGE)	5.924479	$97.40	$30.07	$30.07	6	$13,441.97	$30.07	$1,082.52	$14,554.56
HOUSING, MECHANICAL (SMALL)	5.388425	$118.12	$13.19	$13.19	8	$16,300.96	$13.19	$633.12	$16,947.27
HUB, WHEEL	1.057617	$46.37	$13.19	$13.19	16	$6,398.97	$13.19	$1,266.24	$7,678.40
ARM ASSEMBLY, #1 RIGHT	10.763437	$29.49	$30.07	$30.07	1	$4,070.17	$30.07	$180.42	$4,280.66
ARM ASSEMBLY, #1 LEFT	9.691623	$26.56	$30.07	$30.07	1	$3,664.86	$30.07	$180.42	$3,875.35
ARM ASSEMBLY, #2/7 LEFT	10.802083	$59.20	$30.07	$30.07	2	$8,169.56	$30.07	$360.84	$8,560.47
ARM ASSEMBLY, #2/7 RIGHT	20.611798	$112.96	$30.07	$30.07	2	$15,588.61	$30.07	$360.84	$15,979.52
ARM ASSEMBLY, #3,4,5,6 RIGHT	6.161458	$67.53	$30.07	$30.07	4	$9,319.76	$30.07	$721.68	$10,071.51
ARM ASSEMBLY, #3,4,5,6 LEFT	6.153645	$67.45	$30.07	$30.07	4	$9,307.94	$30.07	$721.68	$10,059.69
WHEEL, SOLID METALLIC	0.490162	$5.37	$1.13	$1.13	4	$741.41	$1.13	$27.12	$769.66
TRACK PADS	1.139322	$486.99	$13.19	$13.19	156	$67,209.77	$13.19	$474.84	$67,697.80
Totals						**$154,213.98**	**$251.19**	**$6,009.72**	**$160,474.89**
Notes									
Storage Cost is cost to store parts in doors on ANAD									
Receipts are costs associated with processing requisitions for parts									
Issue costs are those associated with the actual issue of parts to the user									
Calculations									
Total storage cost = unit cube x qty per system x monthly storage cost (.4567) x 6 months x 138									
Total receipt cost = receipt cost per line									
Total issue cost = issue cost per line x quantity per system x 6 (assuming parts are issued to rebuild an average of 6 M1A1 per week)									
Total DLA overhead = average storage cost + total receipt cost + total issue cost									

(Figure 4 – M1A1 Suspension System Parts Cost Data[30])

averages whose ranges vary greatly. To provide a framework for the snapshot, storage costs reflect storage for 6 months of parts to rebuild 138 tanks, receipt costs reflect cost

for 30 days of parts to rebuild 23 tanks, and issue costs reflect cost for 1 week of parts to rebuild 6 tanks.

Figure four reflects a potential cost savings in excess of $160k, the bulk of which is from warehousing requirements for the parts. As this represents only 11 of the some 12,000+ parts on an M1A1 Tank, imagine the potential cost savings that can be made simply by converting selected parts to AM. It is imperative that a comprehensive analysis be done on parts transition to AM that is based upon metrics that provide the most savings based upon type, frequency of use, size, and composition of parts.

In addition to demand and location, there are two important additional advantages resulting from AM adoption: integration and reversibility. Parts integration through design efforts can potentially combine many parts into one thus reducing the overall cost and potentially the number of AM machining requirements. This also has the potential to reduce costs for those AM produced parts that continue to be vendor supplied. Reversibility is the ability to shrink and expand the manufacturing base based upon need and funding. In the ammunition base, 60-70 percent of vendors disappear in peacetime and it takes 3-5 years to re-create a vendor.[31] A similar metric is plausible for the hard iron base and AM eliminates vendor availability and expertise from the equation thus making it much easier to shrink and then rebuild the base in time of war. While there are many other variables to take into account such as facilities and utility costs, this analysis provides a glimpse into the power and potential that AM could have on the AOIB.

Conclusions

The key to AM's success within the DoD is an acceptance that the technology is revolutionary, not evolutionary or merely manufacturing modernization. Just as the DoD relies on informed predictions of future adversaries to train, organize, and equip its forces, so too must it take the same steps to adopt future technologies that may fundamentally shape how we defend our nation. It is important that the DoD not fall into the "Hype Cycle" and become victim to inflated AM expectations and then simply disregard the transformative nature when expectations are not initially met.[32]

AM could fundamentally change DoD's estimates on the future operating environment. Operationally and tactically, AM could fundamentally change the way logistics units are organized and missions are executed from the depot to the Supply Support Activity (SSA) to the Brigade Support Battalion (BSB). AM could have a transformative and positive impact on the AOIB by:

- Reversing or slowing down manufacturing globalization as products are built on demand at the POR.
- Reducing the risk to the global commons with decreased shipping requirements.
- Reducing the risk to force in a theater of operations with reduction of resupply chains.
- Providing opportunities to reduce AOIB infrastructure as assembly lines are consolidated.
- Decreasing non-mission capable time due to low density parts not on hand.

Funding for the S&T research in AM is at a critical juncture and is more important than ever. The President has stated that in adjusting DoD's strategy and attendant force size, the DoD must make every effort to maintain an adequate industrial base and our investment in science and technology.[33]   Even the DoD's Budget Priorities and Choices document states that the DoD believes that accelerating trends in both technology development and a dynamic threat environment dictate that we must maintain our edge by protecting our investments in developing future capabilities.[34] As such, S&T programs are largely protected within this budget. For the Army in particular, it is expected that it will not increase S&T funding but will protect the $2.2 billion already in the S&T budget for FY12.[35] But, there are many who believe the DoD budget as a whole and S&T in particular will end up being cut given the current Congressional recalcitrance over deficit spending and the sequester.

Consequently, Deputy Defense Secretary Ashton Carter launched a review in December 2012 to determine how, in this tough fiscal environment, the Pentagon could adapt best business practices from the private sector. He stated, "The Pentagon faces an extraordinary combination of management challenges, budget reductions and mounting costs, all while continuing to provide for the national defense. To ensure our success, every organizational leader within DOD should diligently seek opportunities to optimize organizational performance using innovative and cost-effective management tools."[36]   In this vein, there are several policy and organizational ideas that can advance AM and set the foundation for the AOIB to capitalize on this disruptive technology.

Although many components of DoD are beginning to jump on the bandwagon, the agency as a whole does not have a clear strategy or cohesive policy which will allow it to advance beyond the small and specialty components of the Department. Instead, multiple components are working within stovepipes and creating disaggregated strategies that are not nested with those that are actually using the technology. According to Heidi Shyu, "for too long the Army has been disjointed in its modernization efforts with development engineers cut off from those who oversee equipment sustainment".[37] DoD organizations are working with original equipment manufacturers (OEM) to conduct research in the technology and in many cases, are already transitioning parts manufacturing to 3-D printing. But, to what strategic end? This piecemeal approach can be detrimental to the DoD by duplicating efforts and multiplying costs, as well as missing the benefit of what 3-D technology can do as a whole. With possible dwindling budgets on the horizon, a clear strategy and cohesive approach is essential to create efficiencies in the area of research and development as well as eliminating duplicative efforts.

It is hard to objectively deny that 3D printing may indeed bring on what *The Economist* touted as the third industrial revolution. Within research portfolios, agencies are encouraged to identify and pursue "Grand Challenges" – ambitious goals that require advances in science, technology and innovation to achieve.[38] The strategic gain that could be achieved through a focused DoD effort in AM demands a serious, holistic look at including this technology as part of our long term national defense and funding strategies. With the emphasis from top to bottom, an AM future will only happen if we begin to work through the policy, strategy, processes and procedures now.

Path Forward

In order for DoD to take advantage of what is anticipated to be an explosion in the commercial sector within the next ten years, it must take an active approach, partnering with the private sector to keep up with this relatively nascent technology and shaping/guiding it towards DOD's desired end state. The AT&L, AMC, and DA G4 need to develop one single AM strategy for the AOIB that specifically addresses how the AOIB will capitalize on AM and that details the needed infrastructure investments that support it.

Another approach towards a clear and cohesive strategy is for DoD to designate an AM czar within the Office of Secretary of Defense (OSD) to serve as the nexus for "all things AM" and not just the myriad of technical advisory boards that currently exist. This office could then work with policy makers to execute and monitor a strategy which will allow DoD to take full advantage of this technology. Logically, this office would interface directly with the NAMII as DoD's representative.

Together, the AM czar and partners in OSD and the service departments could help explore the various ways in which the technology could be applied across the Department and work with NAMII to help overcome one of the biggest roadblocks to adoption, certification. With so many different models of printers and materials, a clearly identified certification process has to be established so that these parts can be used in support of manned flight. The requirements for military grade equipment tend to be more demanding than commercial grade, and each service may have specific requirements for a similar machine, or a more rigid requirement for something like an

aircraft vice a ground vehicle. Once the DoD identifies uses for 3-D printing, the consequences would certainly be felt throughout the defense industrial base.

The Intellectual Property (IP) issues must be addressed now. Successful designs that happen to infringe on patents are the most likely to be targeted by patent holders. The key will be to prepare the 3-D printing community and the public at large, before incumbents try to cripple 3-D printing with restrictive intellectual property laws.[39] Within DoD, the IP issue is critical. The fact that the acquisition of items has been trending to system buys versus component buys and that DoD has not bought the technical packages to our systems for decades will make it less likely DoD will be able to begin AM conversion unless addressed in the near term and resolved over time. In fact, key commercial AM patents are now expiring providing the perfect opportunity for DoD to take advantage of new opportunities and less expensive AM machines. Within the IP realm, there are two specific areas that need to be addressed; developing an acquisition strategy for CAD files and determining the extent to which scanning and reverse engineering can be legally accomplished (parts can be scanned with a handheld device much like the scanner used by your local grocer and turned into a CAD file with relative ease).

Given that the majority of suppliers are commercial, one way to begin working towards an AM base is to incentivize vendors to provide products produced by AM. The first step would be to update the acquisition instructions contained in Department of Defense Directive (DODD) 5000.01 and Department of Defense Instruction (DoDI) 5000-02 to encourage industry to consider AM in their design efforts. Although DODD 5000.01 states that advanced technology shall be integrated into producible systems[40]

and a broad-based program spanning all Defense-relevant sciences and technologies to anticipate future needs must be maintained,[41] it does not mention AM specifically. As state before, if AM is a revolution in manufacturing, then it should be given due diligence in our acquisition guidance and not just combined with S&T efforts in general. The second step to encourage commercial adoption is incentive based competition to spur R&D into the technical challenges that remain with the technology. As an example, the 2011 Digital Manufacturing Analysis, Correlation, and Estimation (DMACE) Challenge asked participants to submit prediction and model descriptions for the maximum compressive load for a titanium sphere and cube configuration based on DARPA-provided data. DARPA's motivation for the December 2011, $50,000 prize was to challenge the science and engineering community to begin to understand the properties of structures created by AM[42]

The Army should establish a hard iron and an ammunition depot AM Center of Excellence (AMCOE) that will serve as the test beds for AM in the AOIB and linked in with NAMII. It will be able to test DoD and private sector solutions to gage the ability to save the resources highlighted in the earlier analysis. These AMCOEs could guide DoD on the correct path forward by speeding up, slowing down, or adjusting to newer and more promising technologies.

While there are many areas within AM to conduct research, the focus of DoD AM work now needs to be on metals as that is the focal point of much of the AOIB work. The United States is no longer the leader in the world on 3D printing in metals - Germany is now the world leader. The AM systems that produce metal parts is developing very quickly with the most popular being those that use a laser to heat and

melt fine particles in a powder bed. The NIST held a conference in December 2012 to specifically look at metals standards for the industry. There is a technical advisory board within DoD that is looking at developing an AM metals strategy. The DoD should continue to put emphasis in this area.

The DoD has historically trailed the private sector in taking advantage of new technologies and now is the perfect opportunity to reverse this trend. This paper has made clear that AM is a game changer technology that requires much work to establish the building blocks that will allow it to flourish. As the future is always uncertain, when opportunities arise that allow us a glimpse into what is in the realm of the possible, it is imperative that visionaries take note and act.

Endnotes

[1] Barack Obama, *National Security Strategy* (Washington, DC: The White House, May 2010), 1.

[2] (WhatIs.com, the Leading IT Encyclopedia and Learning Center, *http://whatis.techtarget.com/definition/disruptive-technology* (Assessed August 25, 2012)

[3] Barack Obama, *Sustaining U.S. Global Leadership: Priorities for the 21st Century Defense* (Washington, DC: The White House, January 2012), 7-8.

[4] M.G. Mullen, *The National Military Strategy of the Unites States of America: Redefining America's Military Leadership* (Washington, DC: Chairman of the Joint Chiefs of Staff, February 2011), 18.

[5] Heidi Shyu, "Army 30 Year Modernization Strategy," panel discussion, AUSA Annual Meeting, Washington DC, DC, October 2012.

[6] Dr. Christopher Williams, Director DREAMS Lab, “Additive Manufacturing; Technology Overview,” briefing slides, Virginia Tech, October 16, 2012.

[7] Terry Wohlers, “*Wohlers Report 2011: Additive Manufacturing and 3D Printing, State of the Industry*,” Ft. Collins, CO, Wohlers Associates, 2011

[8] D. Mero, "Are You Buying the 3D Printing Hype?," September 7, 2012,

http://www.seekingalpha.com/article/854181-are-you-buying-the-3d-printing-hype

(accessed September 10, 2012).

[9] MCOR Technologies Home Page, http://www.mcortechnologies.com/mcor-technologies-and-staples-division-launch-3d-printing-service/ (assessed November 29, 2012)

[10] Terry Wohlers, "Additive Manufacturing Advances," April 2012,

http://www.sme.org/manufacturingengineering (accessed September 14, 2012)

[11] Patricia Woodside, "Aurora's Additive Manufacturing Wing Showcased in NAMII Announcement," *Aurora Flight Sciences,* August 17, 2012.

[12] "Making Things with a 3D Printer Changes the Rules of Manufacturing," *The Economist"* (April 21, 2012): 1.

[13] Ibid., 6.

[14] Dr. Chris Williams, Professor, Virginia Tech, telephone interview by author, December 1, 2012.

[15] Dr. John Seel, Director, Emerging Capabilities Division, OSD Research and Engineering Rapid Reaction Technology Office, interview by author, September 27, 2012.

[16] Science and Technology Policy Institute, *Additive Manufacturing: Status and Opportunities* (Washington DC: Science and Technology Policy Institute, March 2012), 7.

[17] LTC Brian Lamson, U.S. Army, Office of the Secretary of Defense, interview by author, September 19, 2012.

[18] Alex Davies, "The World's First Electric Vehicle Made of 3D Printing Remarkably Fast," *Business Insider,* August 28, 2012.

[19]Ali Sanders statement to *Inside the Army* Oct 10; posted on InsideDefense.com: October 12, 2012.

[20] Wes Brin statement at the Pentagon in July; posted on InsideDefense.com: October 12, 2012.

[21] Robert Beckhusen, " Pentagon's Plans For 3-D Printers: Mobile Labs, Bomb Sniffers and Prototype Limbs," October 8, 2012, http://www.wired.com/dangerroom/2012/10/printers (accessed November 30, 2012).

[22] Ibid.

[23] Phil Trued, "Additive Manufacturing as a Repair Process" Tank Automotive, Research and Development and Engineering Center (TARDEC) briefing slides, Anniston Army Depot, AL, October 25, 2012.

[24] U.S. Department of the Army, *U.S. Army Organic Industrial Base Strategic Plan (AOIBSP) 2012-2022*, (Washington, DC: U.S. Department of the Army, October 15, 2012), 1.

[25] Under Secretary of the Army Joseph Westphal, "U.S. Army Organic Industrial Base Strategic Plan (AOIBSP)," memorandum for distribution, Washington, DC, October 15, 2012.

[26] Acting Director of the Office of Management and Budget Jeffrey Zients and Director of the Office of Science and Technology Policy Dr. John Holdren, "Science and Technology Priorities for the FY 2014 Budget," memorandum for the Heads of Executive Departments and Agencies, Washington DC, June 6, 2012.

[27] Jim Uribe, Chief, Industrial Planning Division, Joint Munitions Command, interview by author, September 19, 2012.

[28]Ibid., 8.

[29] Thomas Carlisle, U.S. Army Anniston Army Depot, interview by author, January 29, 2013.

[30] Paul A. McMillan, Deputy Commander, Defense Logistics Agency Distribution, Anniston, Alabama, interview by author, February 24, 2013.

[31] Ibid., 27.

[32] Peter H. Diamandis and Steven Kotler, *Abundance: The Future is Better Than You Think* (Free Press, 2012), 35.

[33] Ibid., 5.

[34] U.S. Department of Defense, *Defense Budget Priorities and Choices* (Washington, DC: U.S. Department of Defense, January 2012), 10.

[35]Ibid., 34.

[36] U.S. Deputy Secretary of Defense Ashton Carter, "Terms of Reference, "Applying Best Business Practices for Corporate Performance Management to DoD," memorandum for Chairman, Defense Business Board, Washington, DC, December 22, 2012

[37] Ibid., 5

[38] Ibid., 5

[39] Michael Weinberg, "It Will be Awesome if They Don't Screw it Up: 3D Printing, Intellectual Property, and the Fight Over the Next Great Disruptive Technology," Public Knowledge, November 2010

[40]U.S. Deputy Secretary of Defense Paul Wolfowitz, Department of Defense Directive 5000.01, The Defense Acquisition System, (Washington, DC, May 12, 2003 and certified current as of November 20, 2007), 3.

[41]Ibid., 10.

[42]Science and Technology Policy Institute, *Additive Manufacturing: Status and Opportunities*, 13.